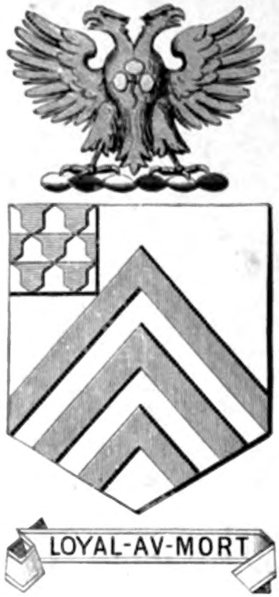
THERMO-ELECTRICITY

ARTHUR RUST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ELECTRICITY:

THEORETICALLY

AND

PRACTICALLY CONSIDERED,

BY THE AID OF

THERMO-ELECTRICITY.

BY

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THERMO-ELECTRICITY:

THEORETICALLY

AND

PRACTICALLY CONSIDERED.

IN studying Electricity, one of the first thoughts to occur is concerning its nature—What is it? So simple, so easily excited, yet so subtle as to evade our keenest analysis, of what does it consist?

Few have attempted to answer the question. Few have ventured to formulate any theory—they merely point to its various laws.

There is a wide divergence between the ideas which, at different periods, have obtained concerning this mighty force. The wondering, awe-struck ancients, spoke of "Jove's thunderbolts hurled from Olympus;" then, generations which followed, of "the attractive property amber acquires when rubbed;" and now, the more scientific moderns, have had the later conception of "the two electric fluids;" but, by common consent, no satisfactory definition has yet been established.

Turning various facts over in my mind during the years 1884 and 1885, at the end of 1885 I wrote this as a theory —"*Electricity is a mode of motion produced by friction of molecules against each other, and conveyed away by the best conductor.*"

Further researches have enabled me to extend this formula; and I now offer the following as more complete—*Electricity is one of the effects of the interaction of atoms and molecules in virtue of their physical properties.* Just as Heat is now known as a mode of motion, and is produced by the friction of matter, we might similarly say that—*Electricity is a mode of motion, a flow of molecular vibrations produced by the friction of molecules against molecules (which by various methods have been brought into different conditions), and conveyed away by the best conductor.*

Of all the various sources of electricity which one can take to prove this theory, and learn to its fullest, even if only to a small extent its nature, which will answer our purpose best? After carefully thinking over the various sources, whether Friction machines, Voltaic cells, Dynamos, Percussion, Vibration, Disruption, Cleavage, Crystallisation, Solidification, Combustion, Evaporation, Atmospheric in all of its varieties, Pyro, Animal, Vegetable, or Thermo-electricity—Thermo-electricity for many reasons appeared the best.

To a considerable extent it was an untrodden field, and one in which there was more promise of fresh facts than in any of the others. This and other things decided its selection. Accordingly, during 1886 and part of 1887, having time at my disposal, I was able to test what I have now advanced.

Most substances have a proportionate conductive energy for heat and electricity. For heat the conduction is slow, while for electricity it is all but instantaneous. The relation between the two appears to be that electricity in its transmission always generates heat, and that heat, whenever it crosses two molecules in dissimilar conditions, or of *dissimilar* specific properties, generates an electric current.

Without passing in review the various metals which have been tabulated by different writers as to their Electromotive

force, and the various forms of Thermo-batteries and Thermo-couples that have been used, tried, or experimented with, and are a matter of history; I may just say that the experiments that are here selected for description have all been made with soft Iron for the first couple, and Zinc-antimony for the second. Many other metals and different substances have been tried during a series of some few thousands of experiments; but to simplify the argument and to clear the ground, I shall only mention a few experiments, and confine them to these two metals, which were chiefly used.

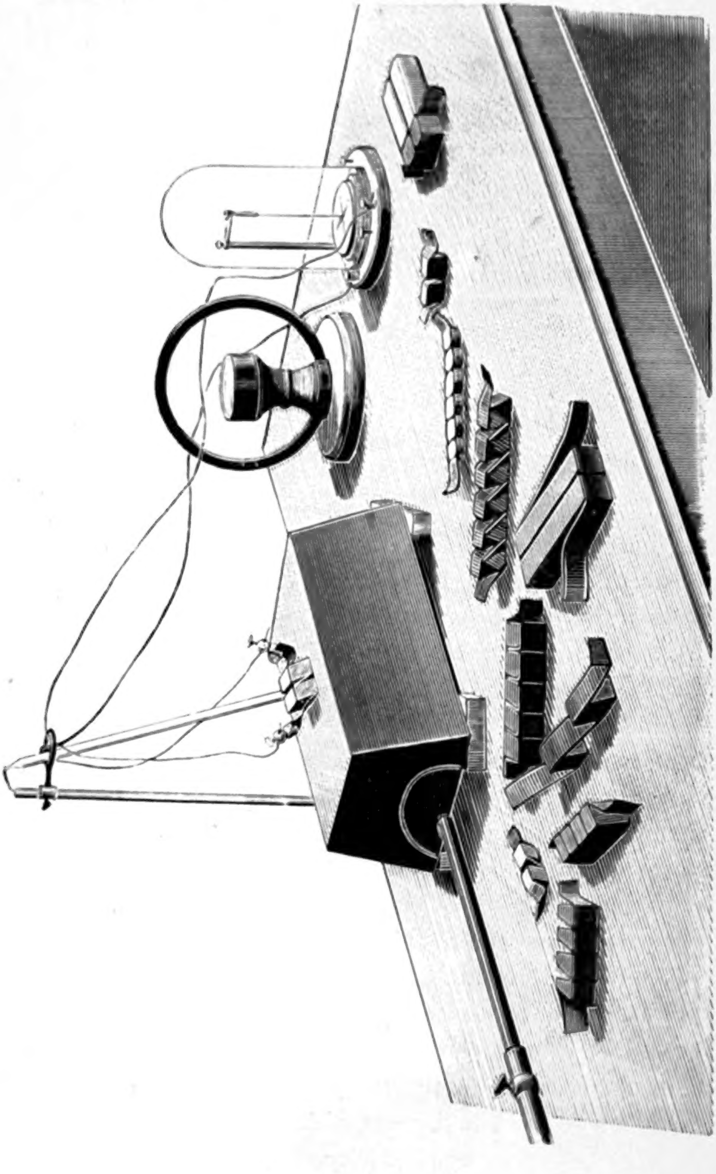
In making any desired couple, it was clearly necessary to see that the Iron was clean; that exactly the same quantity and proportion of Zinc and Antimony were used, and cast as nearly as possible under the same conditions; that a perfect joint was made in casting, so that the Iron and Zinc-antimony were one body. Otherwise many false results would have been registered; and I may mention that all the results described have been tested at least four, and the majority more than a dozen times.

Before we can expect to test any conclusion in this matter, we must quote several experiments that have been made, and in about the same order in which they actually took place. Without this it will be impossible either to explain or understand what actions really go on, though ultimately these will lead up to, and throw some light upon the point we are trying to prove.

In testing the Thermo-couples, we used a Bunsen gas burner to produce the heat, and a piece of sheet iron of convenient shape, resting upon non-conducting supports, to supply the heat to the couples; the usual wires being connected by binding screws to the couples, or leads to the galvanometer, or to the tangent galvanometer; and a thermometer to test the degrees of heat (Fig. 1).

We may take the conductivity of Silver at 100°, that

of soft Iron at 20·18, and that of cast Zinc antimony at about 5·5.



We will mention three distinct forms of couples which will help us to understand the subject.

1. Cut out an angle piece from a sheet of 20 gauge sheet Iron (Fig. 2), say 2½ inches high by 3½ to 4 inches long,

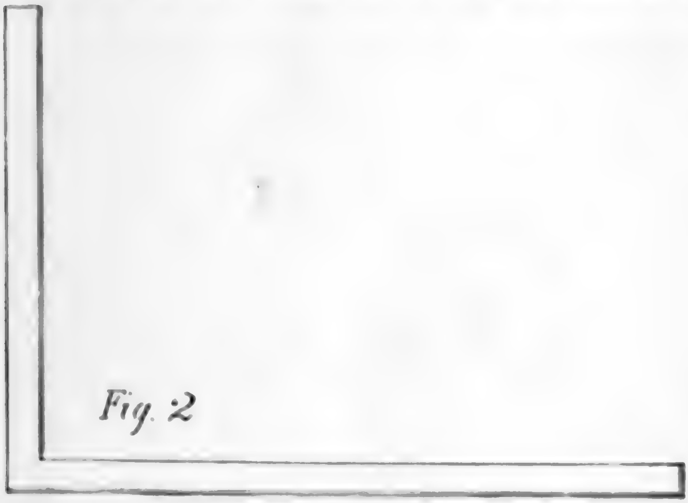


Fig. 2

and 3/16 to ¼ inch wide. Take the bottom end and twist it into a coil (Fig. 3); pour the Zinc-antimony into it, and you have the two metals in combination.

Fig. 3.

If an iron strip, thin pointed, can be cast into the zinc-antimony SLIGHTLY, so that it balances itself, it makes the experiment easier. Connect the two ends up, raise the heating surface to about 375° F., and the galvanometer will give, say 50° galvr. (Fig. 4). Have a pot of melted wax at the same temperatures ready at hand, and plunge the Thermo-couple into it. No E.M.F. is indicated, and at once the galvanometer falls to zero.

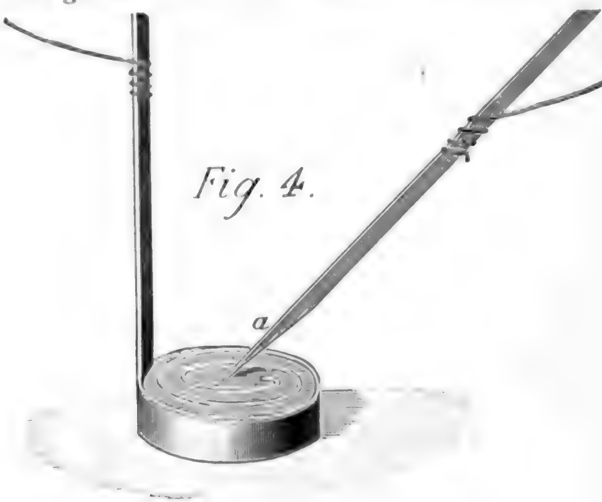


Fig. 4.

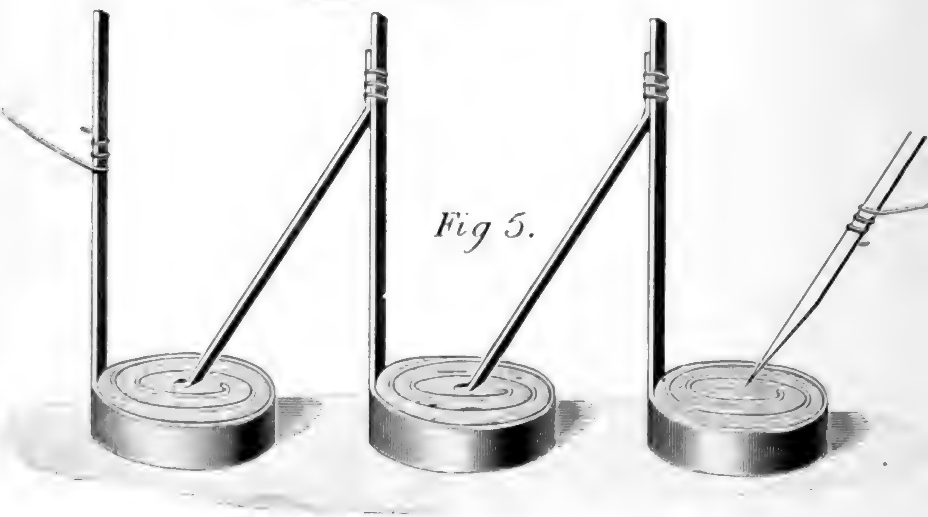


Fig 5.

Take three of these and join them together by a copper wire lead just touching the centre of the next couple (Fig. 5); the galvanometer registers 70° galvr.

Fig 6.

Now take three others, cast firmly, and connected together in casting, thus (Fig. 6), and at 375° F.—what is the result? Is it 70 galvr.? No, galvr. zero!

Take couple Fig. 4 again, with different temperatures, 300° F. shows 40° galvr.; 375° F. shows 50° galvr.; but strange to say, if carried up to 400° F., in spite of Sir W. Thomson, or the "Thomson effect" of the iron being in its favour to indicate a higher E.M.F., the galvanometer falls back to 44° on the scale.

Let us now try what result it will give if we firmly solder the iron lead *a* into the zinc-antimony iron couple. Strange to say the galvanometer falls again, and this time it is at zero instead of at 50 galvr. Why is this? What is the meaning of it?

We now construct another of these Zinc-antimony Iron couples, but instead of pouring the ZA into the Iron coil level, we will more than fill it with ZA (Fig. 7), and raise

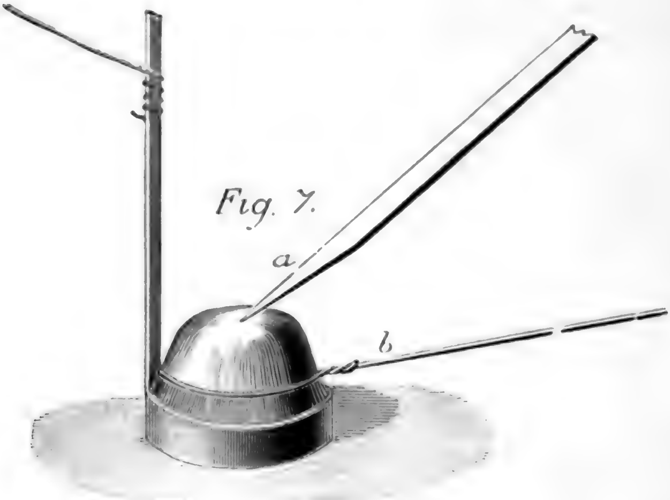


Fig. 7.

the temperature to about 400° F. If we put the iron lead connection on to the top at *a*, galvanometer shows 46°,

Fig. 8.

but if we twist the copper lead firmly round the bottom of the alloy at *b*, instead of 46° being indicated at the galvanometer, we cannot get more than 41-42°. How is this?

Remembering that the conductivity of Iron is almost four times that of ZA, and therefore the more we can bring the molecules of the two metals into friction the greater E.M.F. will be obtained, let us cast a couple in the following form.

Take again a piece of 20 gauge sheet Iron, cut it to pattern (Fig 8.), instead of into the narrow strip; roll this into a coil as before, and we have, after casting the ZA upon it, a couple in this form (Fig. 9). Lay the copper lead

Fig. 9.

(*a*) firmly on, and we have as a result about 40° galvr.—not equal to Fig. 4. Now to understand the reason of this, we must seek an explanation in some other direction.

Before turning to some older forms of Thermo-couples, let us mention a few results from others, which we will call Class 2.

Take some Iron rings ⅝ inch diameter and $^{11}/_{32}$ inch deep

(Fig. 10); cast two Copper leads into the Alloy when casting the Zinc-antimony into the rings. At 350° F. it shows 15° galvr., and at 400° F., 25° galvr. Again with similar rings

Fig 10.

cast two German silver leads into the alloy: at 350° F. it shows 1° galvr.; and at 410° F., 1° galvr. the same. But if one German silver lead and one Copper lead is used, at 410° F. it shows 42° galvr. Construct three of these rings, fasten their leads firmly together, German silver to Copper: at 330° F. we get 50° galvr., and at 410° F., 60° galvr.

Again, let us take a piece of 20 gauge sheet Iron, like

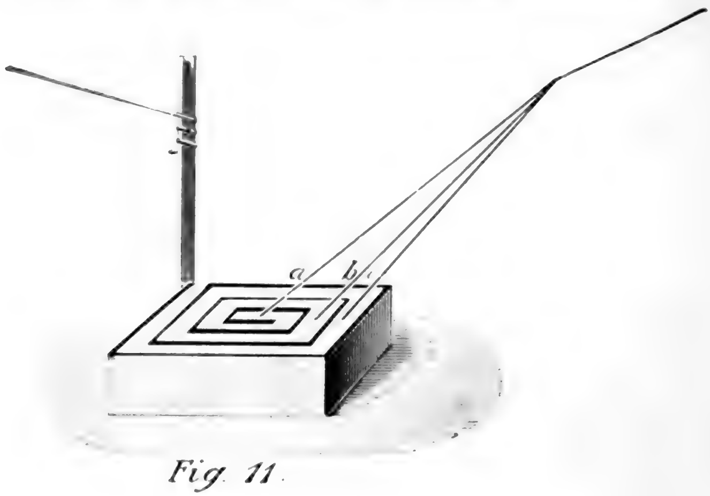


Fig. 11.

Fig. 2, but cut the foot longer, and instead of turning it into a coil, turn it into a square (Fig. 11), lay a copper lead on at *a*, and you cannot get more than 40 to 45° indicated upon the galvanometer. Lay a second lead in connection with the first one at *b*, and you obtain 49° galvr. Lay a third one, also in connection, on at *c*, and 54° galvr. is the result.

These experiments are interesting, but we do not understand the reasons of the results yet, and we must do so to guide us into further knowledge. It must be pointed out that unless the connections are in close contact, the resistance is so tremendously increased that for any commercial purpose the system is absolutely valueless. We will, therefore, turn and experiment upon some of the older form of Thermo-couples, and see what can be learnt from them.

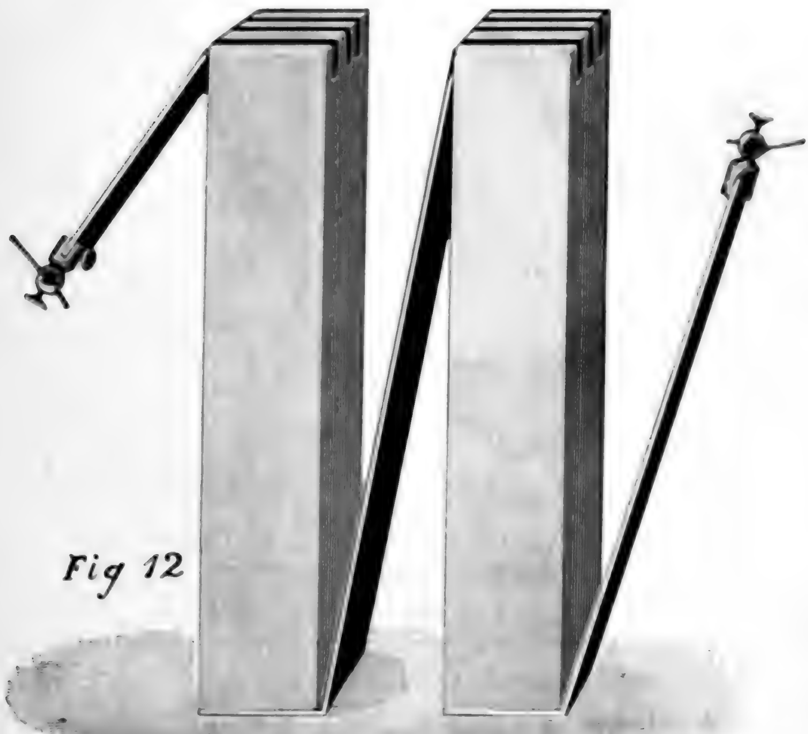


Fig 12

These form Class 3. Remembering the old rule, that the thermo-electromotive force is proportional to the difference of temperature of the junctions, let us construct some couples, 3½ × ½ × ⅝ inches, by taking 18 gauge sheet iron, and cutting the ends into three slits, which, when twisted and having the ZA poured in, will form the junctions (see Fig. 12). Heat up to 375° F., and we have only 33° on the galvr. This is clearly going backwards. Now let us try half the length of couple, say 1¾ × ¾ × ⅞ inches from 20 gauge sheet Iron (Fig. 13), connect up, and at

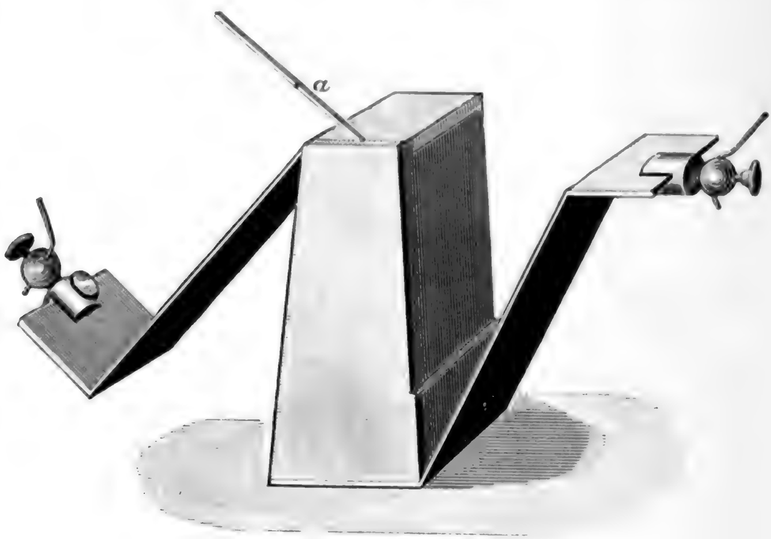


Fig. 13.

the same temperature we have 42° galvr., or a little better than the result of the longer ones (Fig. 12), which is in direct contradiction to the recognized laws on the subject.

Now let us take wire gauze double, instead of 20 gauge sheet iron, say about 16 mesh, and construct 2 couples, say 1½ × ⅝ × ⅞ inches (Fig. 14). Try them at 410° F., and we get 49 to 50° galvr. This is better. But we will try

and get the molecules into a state of still greater friction one with the other. Remembering that the conductivity of Iron is 20·18 and ZA 5·5, and that the larger the Iron surface

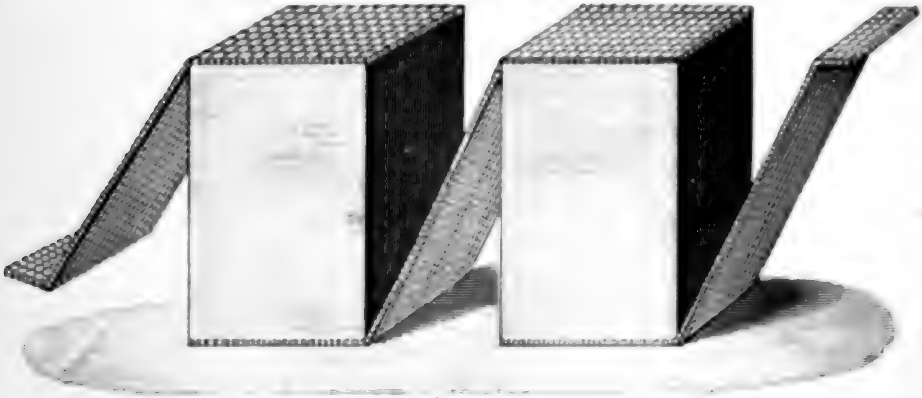


Fig 14.

friction against the ZA, the greater the E.M.F. we might expect to create, let us construct an element 1¾ × ⅝ × ⅞ as the last and with the same materials. Let us insert, upright, into the ZA a number of pieces of this Iron wire gauze, alternately 1 and 1⅜ inches long, connected to the bottom Iron (Fig. 15). Heat up as before. We look anxiously

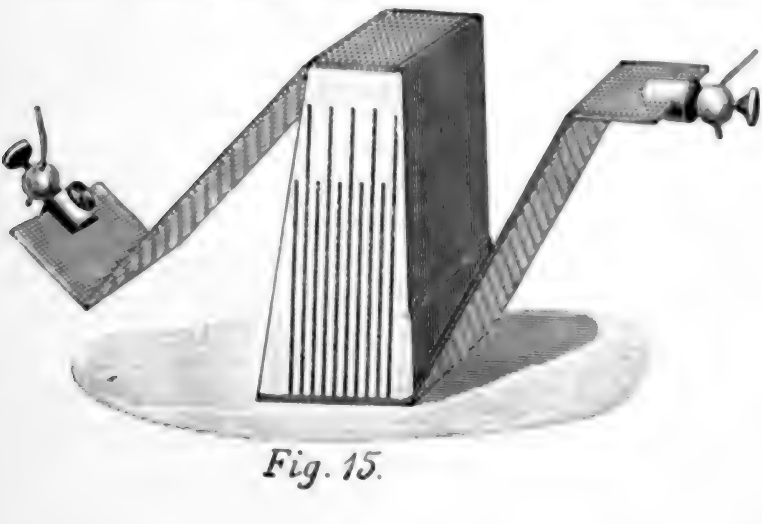


Fig. 15.

at the galvanometer. It begins to rise slowly, slowly, slowly, and stops, instead of at 50, at 8°. Why is this? We cannot as yet the reason see! The Iron being the best conductor of heat, its molecules SHOULD (in Fig. 15), according to the theory advanced, strike the molecules of ZA, and generate a greater E. M. F. as the consequence. How can we get at the truth of this matter with Fig. 15 staring us in the face?

With regard to the molecules of bodies, three different states of aggregation present themselves: First, the solid state; second, the liquid or fluid state; third, the gaseous state. These experiments have only to do with the first or the solid state, although, of course, the two latter come into play in many of the other sources of electricity. From considerations based upon various physical phenomena, Sir W. Thomson has calculated, that, in ordinary solids and liquids, the average distance between contiguous molecules is less than one hundred millionth, but greater than the one two thousand millionth, of a centimetre; and to form an idea of the size of the molecules, Sir W. Thomson gives this illustration:—"Imagine a drop of rain, or a glass "sphere, the size of a pea, magnified to the size of the "earth, the molecules in it being increased in the same "proportion. The structure of the mass would then be "coarser than that of a heap of fine shot, but probably not "so coarse as that of a heap of cricket balls." Professor Tait, when making the same calculation, suggested marbles. The number of molecules in a cubic inch of gas at 0°C. temperature and 760 millimetres pressure, has been calculated to be about one hundred thousand million million million, or 100,000,000,000,000,000,000,000 (10^{23}). The molecules of a gas are always in a rapid motion. The mean velocity of hydrogen molecules at 0°C. and 760 millimetres is about 6,000 feet, or $1^1/_7$ miles per second (the length of its path being .0,001,855 millimetres, and nine thousand four hundred and eighty millions [9,480,000,000] for the number of its impacts).

These molecules and atoms are what we are dealing with, and their extreme minuteness it is which makes it so difficult for the mind to conceive them, and to understand in any way the part they play.

We construct four cubes, one each of Iron, and ZA, in ⅜ inch, and one each in 1 inch cubes. After putting a little wax on the top of each, and placing all at the same time on the heated surface, we find that with the ⅜ inch cubes the wax on the top of the *ZA* melts first; but with the 1 inch cubes the wax on the *Iron* melts before the wax on the ZA.

Now we construct two bars ½ inch square, one of soft

Fig. 16.
¼ scale.

Iron, and one of Zinc-antimony, and fix upon each bar peas, by tallow, sealing wax, or any suitable material, ¼ inch apart, the bars being held by convenient stands. We light a Bunsen burner to produce the heat, and place it exactly in the centre of the space between the two bars. What are the results? Of course, if we had not tried the cubes experiment we should have said that the Iron, being the better conductor, would take the heat first; but no, to our surprise, the peas on the bar of ZA fall first, about in this order:

1	2	3	4	5	6	7	8	9	10	11	12	13	14
ZA	I	ZA	I	I	I	ZA	I	I	I	ZA	I	I	I

15	16	17	18	19	20	21	22	23	24	25	26	27 to 35
ZA	I	I	I	I	ZA	I	I	I	I	ZA	I	Iron.

We try this several times, in several ways, with different degrees of heat, and different sized bars ; also with shot, set $\frac{1}{8}$ inch apart, instead of peas at $\frac{1}{4}$ inch, but *always* with a result closely similar. Singularly enough, we find the heat takes from twice to four times as long to travel to the last pea that falls from the Iron bar, as to the last pea that falls from the ZA bar.

Fig. 17 shows the Iron and ZA bars put side by side, and the proportionate rate the heat travels upon each, as it arrives at *a*, *b*, *c*, *d*, etc., on each of the bars, at about the same time.

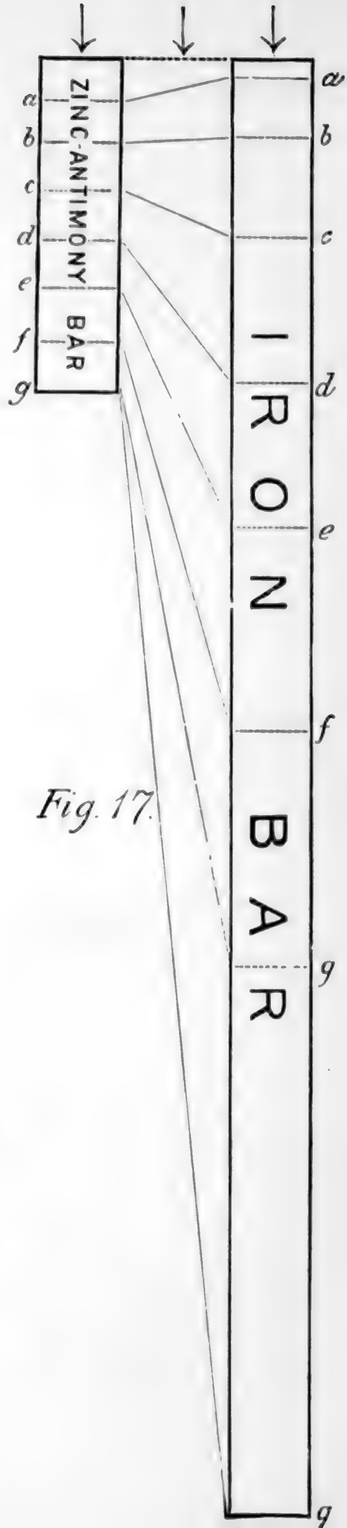


Fig. 17.

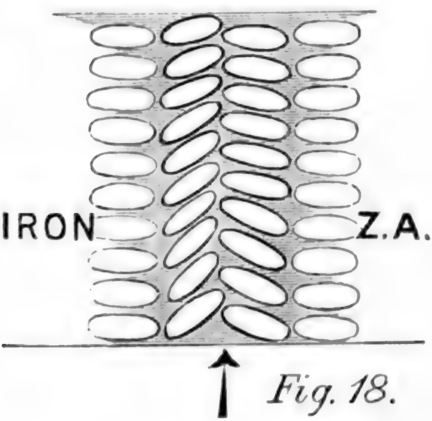


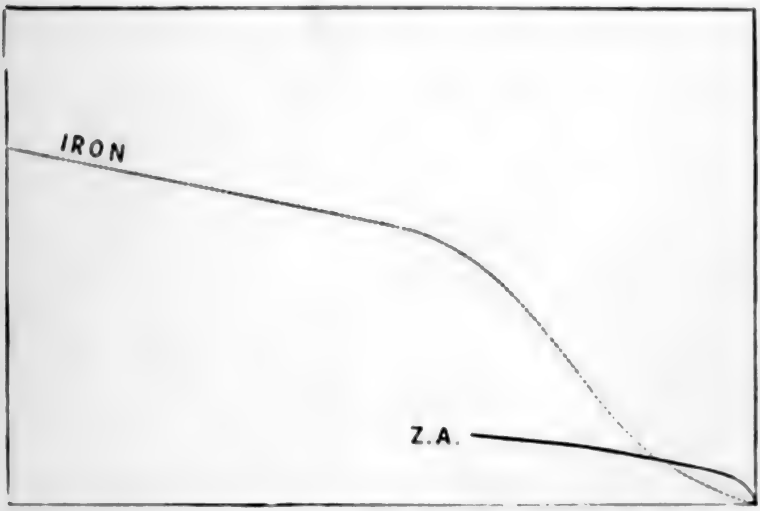
Fig. 18.

Fig. 18 gives a very rough idea of the proportionate

stress that the ZA molecules exercise upon the Iron molecules, showing that the first contact of heat is by far the greatest.

Fig. 19 contains two curves representing the rate at which the heat travels along the bars of ZA and Iron. But, of course, the rate varies according to the temperature and according to the iron used, whether hard, soft, or annealed

Fig. 19.



In these striking facts we think we have light cast upon this subject, and shall find that we have something to work upon. We learn that ZA, having fewer atoms than Iron, the nearest portion of the ZA bar is heated before a similar portion in the Iron bar, although the Iron is almost four times a better conductor of heat. So that it is not the molecules of the Iron swinging in friction or with vibratory stress against the ZA that causes the flow of electricity, but it is the molecules of the ZA swinging in friction or with vibratory stress against the molecules of the Iron. This can further be explained. In this

combination of ZA and Iron, ZA receives and loses heat first, and the molecules have taken up their full complement of heat before the Iron in the earliest portions of a short thermo-couple junction; Heat, the motive power, is then able to do work, and drives them in frictional stress against their slower but more enduring neighbours, which is the true explanation we have been looking for.

Therefore, understanding now the action of this combination, we simply have to continue more experiments, and to make more Thermo-couples to conclusively prove our point, for the greater the friction and flow of molecular vibrations we can really get into play, so long as there is a continuous flow, and no counter E. M. F. or drag, brought about, the greater will be the E. M. F. produced.

We might almost compare the molecules of the ZA and Iron to two sets of cog wheels, with their cogs interlocking, but only vibrating, not revolving. The ZA cogs, moving the sooner, act upon the series of Iron cogs, and therefore the faster and stronger the ZA cogs run, the greater the friction upon the cogs of the Iron, and the greater the E. M. F. generated. Or we might compare them to two sets of springs interlocking—the ZA springs starting first, move in *continuous vibration* upon the Iron springs. Evidently, then, if any of these Iron cog wheels in any part of the machine (Thermo-couple) have a quicker and more powerful swing than the ZA cogs, a counter force is brought into play, and a smaller molecular stress, or E. M. F. is produced. So that, if we can by any process, or by any means, get the Iron cogs to vibrate more powerfully than the ZA cogs, we shall still have an electric current set up, because the molecule cog wheel, or the molecule spring, is doing work and setting up a flow of molecular vibrations, though in this latter case the Iron molecular cogs are the motive power in friction or with vibratory stress against the ZA cogs, and not the ZA in friction or with vibratory stress against the Iron.

With these explanations, before making new couples, we will look into the reason of some of the results indicated in some of the old experiments that have been described. In Figs. 4 and 5 the ZA cogs move sooner, and have a more powerful swing than the Iron cogs; they take up the heat and lose it more quickly than the Iron, and the potential stress, or E. M. F., having been generated, it is taken away by a touching contact, and the E.M.F. created is recorded in the galvanometer. Now what takes place when Fig. 6 is brought into trial, or when the leads of Figs. 4 and 5 are soldered so as to make a continuous connexion? Simply this: the iron or copper lead becomes an incorporated part of that couple, and although there are cog wheels always in action in the couple, the Iron cog wheels of the lead, being at the same temperature as the ZA, are not at work, and no E. M. F. is indicated. We will show this, but without using solder. Take Fig. 4, and instead of a thin copper or iron lead, let us use a fine strip or bar of copper, and let the end of this touch the couple (see Fig. 20); what does the galvanometer indicate? 40 galvr.!

Fig. 20.

Now let us place this copper bar flat across the couple (Fig. 21); the galvanometer falls to 3°. If it had been

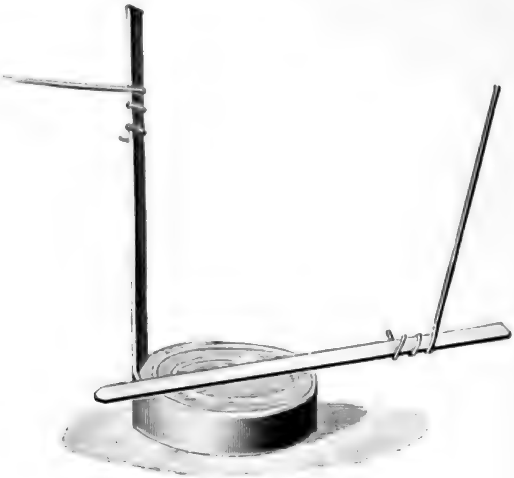


Fig. 21.

soldered it would have indicated zero, but some small air spaces are between, and some few of the ZA cogs are yet moving, or in the ascendency. Of course the main cause of this alteration is the change of the position of the copper bar, which in the second case allows the Iron molecules to be almost the same temperature as the ZA molecules, and which, therefore, is acting as a drag, *i.e.*, preventing the ZA molecular cogs from doing work upon the Iron molecular cogs. Fig. 7 shows the same cause at work in a modified form.

The galvanometer shows (Fig. 4), at 375° F., that the ZA molecular cogs have the most power; but when the couple is plunged, at this temperature, into the pot of melted wax, all molecules, both ZA and Iron, are brought to the same degree of heat, therefore no molecular stress, ZA against Iron or Iron against ZA, is possible; the two sets of

molecules in this couple are now in a state of unison, and for that reason no electrical energy is generated.

Now let us take Fig. 9, but transformed into a new couple, breaking off the outside ZA (Fig. 22). When we tried Fig. 9

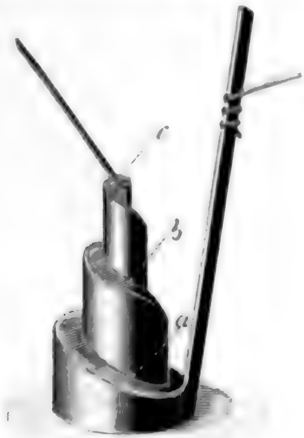


Fig. 22.

couple in the original form it gave 40° galvr., but now, taking the spare lead and touching the alloy ZA at the top *c*, it gives about 41°, or similar results to the old Thermo-couple. Now at *b* it gives, after the galvr. has come to rest, 44°, and at *a* 48°. The explanation of this is the same. At *c*, the Iron has brought up the heat and is causing a drag upon the ZA cogs when the galvr. gives 41°; at *b* this drag is smaller, and gives 44°; at *a* it is smaller still and gives 48°; and no doubt, had we tried the ZA lower down, where there would be still less drag or back friction, this furnace of cog wheels would give 50° at least.

Fig. 10, after allowing for the thermo properties of the metals, we think explains itself. Fig. 11 shows, in this particular form, that all the E. M. F. generated is not taken off by one lead.

In Fig. 13, instead of connecting up both ends, let us

fasten only one end to the Iron, and with the loose end touch the Alloy at *a*. What do we now get?—48° on the galvr. instead of 42°! This shows that the top Iron has taken up a great deal of heat, and brings in a counter E. M. F. or drag, and thus prevents the full working of the ZA cogs, as indicated by the galvanometer.

We have seen that these experiments do not bear out the old law viz.: "That the greater difference in temperature between the two ends of a couple, the greater E. M. F. will be produced." For we have shown (Fig. 12) that couples 3½ high, give 33-34° on the galr.; (Fig. 13) 1¾ inches high, 42° galr.; and (Fig. 14) 1½ inches high, 49-50°. But we find that if we make the wire gauze into Thermo-couples 1⅛ inches high, we shall have a still *less* difference in temperature between the two ends of the two couples, but we increase our E. M. F. considerably; the same heat easily showing 60° galr., Two couples with heat 450°F. can be made to indicate 80° galr. At this temperature the thermo properties of the Iron are of course much improved by the Thomson effect. Indeed, rightly applied, 100° difference in temperature gives better results than 200° applied wrongly.

The true law of thermo-electricity is—

THE ELECTRO-MOTIVE-FORCE IS PROPORTIONAL TO THE RATE OF SPEED AT WHICH HEAT PASSES THE TWO JUNCTIONS.

Turning to Figs. 16 and 17 for a moment, let us notice that the peas *always* fall off the ZA first. This shows, as we intimated before, that they receive the heat sooner, and are soon hotter than the Iron molecules, and that the ZA molecules (Fig. 19) strike in frictional stress against the Iron. But it shows more; for if the Iron is allowed to penetrate into the body of the ZA, a counter E. M. F., or drag, is set up, and the greatest E. M. F. is produced by the first thrust of the heat of the ZA molecules against Iron. Everything

favourable to that naturally produces better results, by promoting greater continuous friction of the molecules.

Let us now take 16-mesh Iron wire gauze as before, to form two sets of couples, and fold it in three. In one case, folded loosely and not pressed together, the Iron gauze will show as in Fig. 23; in the other, pressed or even hammered

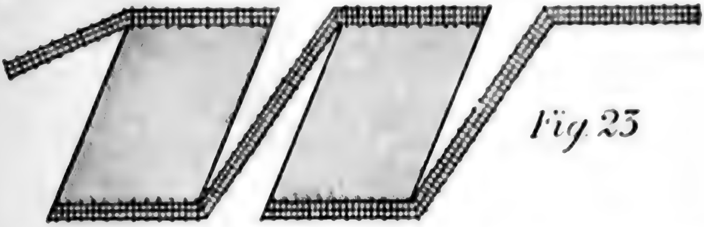


Fig. 23

together, the Iron gauze will show as in Fig. 24; now let us cast six couples upon each of these, and to bear out

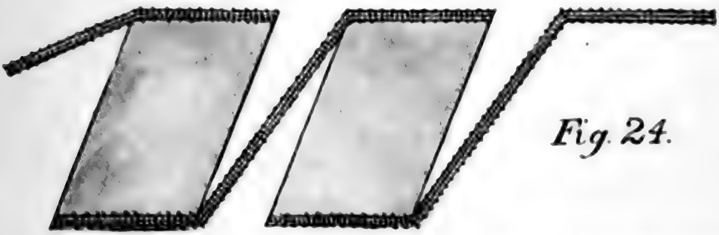


Fig. 24.

natural deductions from Figs. 16 to 19, the six couples cast to the pattern Fig. 24 should show the best results, or a greater E. M. F.

Let us heat them both up to about 325° F.; these are the results :—

	% Heat.	Galvr.	Tang. Gal.	Gal. & 1000 ohms.
Six couples Fig. 23...	325° F.	75°	6½° and 35¼°	30°
Six couples Fig. 24...	„	77½°	7½° and 44°	32½°

Very many other experimental couples were constructed, all the tested results of which indicated analogous conclusions. We thus see, comparing these last facts with Figs. 15 and 22, that the investigations are abundantly verified.

I made another experiment upon one of the same kind of couples, trying what effect could be obtained by putting it into a powerful vice. After carefully insulating the jaws, connecting the leads up from the couple to the galvanometer, and putting considerable pressure upon the handle of the vice, I found about 2° indicated. Left thus for about ten days the same current was shown; left again, but this time for three months, all the current had gone. But on unscrewing the handle of the vice, the galvanometer indicated a small reverse current.

I have thought it better, as mentioned at the outset, to confine our attention to these two metals in conjunction with each other. In dealing with other metals or alloys, their physical properties and characters have to be carefully examined and thoroughly enquired into, to understand, in a small measure, what work their atoms and molecules are doing.

It is most interesting to turn up the experiments of Erman, who showed that a violent blow struck by one substance upon another, produces opposite electrical states on the two surfaces, and found that taking the thermo-electric series of metals, each substance will take a + charge on being struck with one lower on the list. Bismuth, German Silver, Lead, Platinum, Zinc, Copper, Iron, Antimony, etc., etc. This again goes to prove the theory with which we started, since the violent blow given, places the molecules of each of the two metals, each substance having physical properties of its own, in a state of stress, so that if these blows could be continuously delivered, cog wheel friction would be set up, and an E. M. F. produced. Since this stress—this state of molecular tension—this static electricity remaining—always runs to the weakest part of any particular body, it naturally remains upon any point of a large body where the molecules are most at liberty to come into play, rather than in the mass of the body itself; and perhaps the

molecules of the larger part of the body are acting as a stress upon the molecules of the pointed or smaller parts of the body.

We think we have now shown what we started to prove. The molecular movements that take place in a Thermo-couple are only a sample of what must take place in all of the various other sources of electricity mentioned at the outset. The same kind of actions of molecules and atoms are brought into play, in the chemical combinations of the Voltaic cell, in the revolving magnets of a Dynamo, in the heated junctions of the Thermo-couple, and in every other source of electricity.

There are not two electricities but one.

The solid earth, with its immense storehouse of quadrillions of trillions of billions of molecules, may be taken, for sake of argument, as resting at zero, and when molecules, by what means soever, are placed in a state of potential stress, which we call +, or a lacking void, which we call −, mother earth when brought into connection with them, is ever ready, so far as it is able to give them what they require, and let them, in a measure, return into a state of rest. With the earth's great storehouse to help, we are thus able to bring "the Thing called Electricity" into use for the various purposes for which it is now employed.

We think these explanations point to the fact that the vibrations produced by heat upon molecules and atoms, similarly constituted, are of the same kind and act together; but when these atoms or molecules are differently constituted, so that they respond to the heat vibrations in different ways, the different set of molecules act upon one another, and bring into play a different set of physical elastic properties, which produce other molecular motions, —which new molecular motions or vibrations continue in a flow, right along the conductor, to its destination, and which is the current electricity of our present telegraph

service. If a too strong potential is turned upon a thin wire, the impact on the molecules or cogs, is more than they can bear, so that the wire is unable to carry the potential; the atoms and molecules being pushed out of the angle to which they are capable of swinging, the molecules come into counter friction with each other, producing heat, which, if allowed to go on, raises the wire to a state of incandescence, and eventually burns it up.

Of course, current electricity or molecular vibrations take the easiest path, and naturally those on the outside of the wire, in contact only with the atmosphere and the ether, vibrate the most easily. Thus it is made clear that when the electric wires are covered, as in cables or under-ground wires, the covering interferes with the free molecular stress or vibration, and slows the telegraph speed, as is so well-known.

An illustration has sometimes been given of current electricity as a series of billiard balls connected together; hit one, and the last one replies. *Such is not a true representation of the case.* It rather resembles a series of cog wheels; vibrate one, and the last molecular cog at the other end of the metallic connexion turns, vibrating in reply. The billiard ball illustration would more aptly apply to the telephonic instruments, which occasionally have been arranged to work on the same wire and at the same time as the cog-wheeled vibratory current electricity.

Professor Clausius has stated his belief that there are only two material forces at work—heat and electricity. I believe there is only one (save the physical material properties of matter), viz.: heat; and that electricity and light proceed from it.

The relative positions of molecules and atoms in solids being fixed, and contiguous to each other, when the expenditure of force comes, effects are communicated that are well-known. Molecules in the liquid state, more readily glide past one another, and they assume the form of any

vessel in which they are placed. Molecules in the gaseous state, are still more susceptible of motion, depending upon the pressure to which they are subject; but a molecular solid passes into a liquid before it can pass into the gaseous state, so in the gaseous state the gaseous molecule must still retain some connecting link with its liquid molecule, and this again with a solid molecule. Professor Tyndall has ably and conclusively proved this, and has shown that molecules, after they have been released from the bonds of cohesion and reduced to a state of vapour, still retain, in this gaseous form, many of the differences and peculiarities that they possess in the solid form.

We have shown that with a small couple a moderate current can be produced. Imagine large numbers of these acting with each other, or huge quantities of matter in electrical *stress* in the earth, and we will get some idea of one of the powerful factors which must have been at work in the formation of our world. And this idea will be strengthened by aid of the belief that when bodies fall into the sun, forming sun spots, with their gaseous flames of 50,000 to 350,000 miles in length, huge molecular electrical friction is set up, generating such vast electrical energy, that it is communicated through a distance of 93,000,000 miles, and when it reaches our earth the effects are felt by the increased daily variations of our magnetic needle.

Regarding the beautiful electrical experiments in vacuum and partial vacuum that have been made by Prof. Crookes, are not the results, with these views, what might have been expected? and if an ABSOLUTE VACUUM can be formed, which would be analogous to taking all molecules and atoms out of existence in that space, the certain result would be, no electric current could pass—*there are no molecules and atoms* to convey the electric current across such a vacuum to the second pole.

Without enlarging more fully at present upon these

investigations, does not Electricity, with the conclusions derived from the new facts described, become a much simpler and a more understandable science than what we have hitherto been accustomed to think it is?

I may state that I have in the course of these experiments, among other things, used as one item 18 cwt. of antimony; and to test conclusions, I constructed an Electrical Furnace which has 6,000 elements, and of which a copy from a photograph is annexed. The heater, which occupies the interior of the cylindrical arrangement of elements, is a slow combustion stove of particular construction. In the centre it is fed by a continuous tube charged with coke from the top; this opens at the end into a fire-box or basket closed at the bottom by bars, and on these bars are placed a cone which causes an outward distribution of the fuel as it descends from the supply-chamber. Around this supply-chamber there is a concentric casing filled with sand, which retains the heat for many hours after the fire has burnt out, and prevents the heating and cooling from taking place too rapidly. Outside this last casing, there is again another casing concentric with it, and between these are three spiral flues. The heat and products from the fire ascend by these flues, and at the top of the casing there are three apertures by which the products of combustion are delivered in a common up-take which leads to the chimney.

In this way, and by the help of regulating flues, the exterior casing is very equally heated; a sufficient temperature is easily maintained, and this without any risk of overheating the elements. The inner faces of the thermo-elements are in close proximity to this heated casing, although not electrically connected with it. Thus the requisite heat is supplied to the couples, and each row being connected together by binding screws, for convenience, the total number of elements can be arranged row by row, either in one circuit or multiple arc as desired. The

electrical current flows as described, and can be employed for any purpose for which it is required.

The stove simply as a stove, was found capable of producing a tremendous heat, and from an actual trial in testing, before the thermo-elements were added, allowing all the dampers, etc., to be out, and giving it full play, within twenty minutes of lighting the fire, such heat was generated that lower parts of the iron furnace melted like wax.

This Electrical Furnace, this Magnopile, gave in actual work an E. M. F. of 96 volts, with a resistance of 11·5 ohms. This resistance need not have been more than 10 ohms, and better results can yet be obtained. The cost was at the rate of about *6d.* per 10 hours. Prof. Silvanus P. Thompson who, on several occasions, has kindly given me suggestions in the construction of the Magnopile, advises me to make it known. Through other pressing engagements, I have been taken completely away from this work, and have not had opportunity to complete it commercially, but it is certainly only a matter of time and detail. A Magnopile will assuredly be completed, and will, in the future, be a commercial success.

After attending the British Association this year at Bath, and hearing the address of the President of Section A, describing electricity as "The Thing called Electricity," I am induced to offer, after a two-years' silence, these facts and thoughts to the scientific world—the true explanation of the phenomena of Electricity.

Eversleigh, Leicester,

October, 1888.

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